



Intrusion of lamprophyre dyke and related deformation effects in the host rock salt: A case study from the Loulé diapir, Portugal

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ABSTRACT

A rock salt–lamprophyre dyke contact zone (sub-vertical, NE–SW strike) was investigated for its petrographic, mechanic and physical properties by means of anisotropy of magnetic susceptibility (AMS) and rock magnetic properties, coupled with quantitative microstructural analysis and thermal mathematical modelling. The quantitative microstructural analysis of halite texture and solid inclusions revealed good spatial correlation with AMS and halite fabrics. The fabrics of both lamprophyre and rock salt record the magmatic intrusion, “plastic” flow and regional deformation (characterized by a NW–SE trending steep foliation). AMS and microstructural analysis revealed two deformation fabrics in the rock salt: (1) the deformation fabrics in rock salt on the NW side of the dyke are associated with high temperature and high fluid activity attributed to the dyke emplacement; (2) On the opposite side of the dyke, the emplacement-related fabric is reworked by localized tectonic deformation. The paleomagnetic results suggest significant rotation of the whole dyke, probably during the diapir ascent and/or the regional Tertiary to Quaternary deformation.

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1. Introduction

The relationship between a dyke and its host rock in the upper crust is formally described as the propagation of a fluid-filled fracture in a linear elastic medium (Rubin, 1993, 1995), while inelastic deformation in the host rock, resulting in a variety of brittle deformation features, characterizes the shallow crustal levels (Baer, 1991; Correa-Gomes et al., 2001; Pollard, 1987; Rubin, 1993; Weinberger et al., 1995). However, in some mechanically weak rock types, especially in rock salt, the upward curvature of rock salt layers adjacent to the dyke indicates a viscous drag accommodated by recrystallization in ductile creep regimes (Knipping, 1989). The magma flowing through the dyke conduit modifies the conditions in the narrow zone of the host rock in terms of stress field, fluid activity and temperature, which can cause deformation and melting of the host rock (Knipping, 1989). This type of contact zone can contribute to the understanding of the magma ascent in deeper crustal levels, and also to the description of deformation mechanisms of the rock salt at high temperature. The mechanisms of such ductile deformation in the vicinity of a dyke have not yet been studied in detail.

The deformational behaviour of rock salt depends on temperature, confining pressure, grain size and solid solution impurities and is strongly stimulated by the presence of fluid at the grain boundaries (e.g. Marques

et al., 2013; Pennock et al., 2005, 2006a, 2006b; Schlöder and Urai, 2007; Schlöder et al., 2007; Ter Heege et al., 2005a, 2005b; Trimby et al., 2000; Urai et al., 1987, 2008; Wenk et al., 2009). The quantitative characterization of the fabrics is a necessary prerequisite for identifying the combined influence of the above stated physical conditions, and correct extrapolation of the deformation mechanisms from the conditions of experimental deformation (e.g. Desbois et al., 2010; Passchier and Trouw, 2005; Urai et al., 2008). The lack of visible strain markers in rocks is nowadays often compensated by the determination of their low-field anisotropy of magnetic susceptibility (AMS; for review see Borradaile and Henry, 1997; Borradaile and Jackson, 2010; Hrouda, 1982; Tarling and Hrouda, 1993). AMS has a great potential to reveal the internal fabric in rock salt, despite the very weak magnetic susceptibility. There are very few studies on the magnetic fabric of rock salt (e.g. Hrouda, 2004; Hrouda et al., 2001), therefore this is a unique opportunity.

The present paper reports on a detailed study of the interaction between the intrusion of a dyke in salt rock and the structural evolution in the Loulé Salt Mine in Southern Portugal. We used a combination of magnetic studies (comprising AMS, rock magnetism and paleomagnetism) with the quantification of rock microstructure (from the lattice and shape preferred orientation). The aim of this work is to pinpoint and characterize the internal fabrics promoted in the host rock salt by dyke intrusion and subsequent deformation processes.

An AMS study was first performed, as it is a fast and effective method to determine orientation and strength of rock fabric. The tectonic

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evolution of the salt/dyke system after the dyke intrusion was also characterized by means of paleomagnetism. The quantified rock salt microstructure has been compared with the AMS data. A detailed microstructural description together with the CPO provided information about conditions and processes that led to salt fabric formation. Finally to confirm or disprove the deduced deformation mechanisms and conditions, mathematical modelling of the temperature field inside and outside the dyke after its intrusion was carried out.

2. Geological background

The Loulé salt diapir in the Mesozoic-Cenozoic Algarve basin (Fig. 1a) was chosen as case study to show the relationship between mafic dyke emplacement and host rock salt deformation. This basin, consisting of two superimposed Mesozoic and Cenozoic sedimentary sequences (Terrinha, 1989), is the outermost geological province of southern Portugal. It is mainly filled by marine limestones, marls and sandstones accumulated during the Late Triassic to Quaternary. In addition, it comprises Hettangian evaporites interbedded with siliceous sediments of a volcano-sedimentary complex. The basin developed as a result of extensional tectonics associated with the breakup of Pangaea and development of the westernmost Neo-Tethys from Early Triassic to Late Cretaceous times (Terrinha, 1989). The first stage of deformation during the Middle Jurassic (the Dogger) resembles the extension of crustal tectonic blocks, promoting a downward movement of salt along an inclined surface, forming recumbent folds with horizontal thrust sub-vergence (Terrinha et al., 1994). Later, during the Campanian (Miranda et al., 2009), the evaporites were intruded by lamprophyre dykes that belong to a small group of alkaline intrusive rocks, geochemically similar to that of the nearby Monchique complex (Martins, 1991). For the dykes, the crystallization age is 72 Ma based on K–Ar biotite dating (Miranda et al., 2009). According to Terrinha et al. (1990) and Terrinha et al. (1994), the diapiric ascent of the salt body possibly

dates from the Upper Cretaceous to Early Tertiary. Finally, the Loulé diapir records Tertiary to Quaternary deformation related to a N–S shortening associated with an E–W regional extension, resulting in a penetrative fabric in the salt rocks.

The studied lamprophyre dyke is 3 m thick, and has an orientation $330^{\circ}/80^{\circ}$ (dip direction/dip). At both dyke margins, the texture is aphanitic with devitrified volcanic glass and abundant euhedral as well as skeletal xenocrysts of olivine and olivine xenoliths, with serpentinized olivine xenocrysts at the SE margin. The dyke centre shows subophitic texture of plagioclase laths, needle crystals of amphibole and large anhedral crystals of biotite, with high amount of volcanic glass. The olivine xenocrysts are significantly less abundant in the dyke core. Only brittle structures have been observed in the dyke itself (Fig. 1b). Fractures within the dyke are filled with halite. Within the host salt rock close to the SE dyke margin, angular fragments of lamprophyre of various sizes can be observed. In the same area, smaller dykes appear strongly dismembered within the salt.

Samples were collected in rock salt and within and around a lamprophyre dyke in the Loulé Mine. Core samples were obtained using a gasoline-powered portable drill (profiting the very efficient ventilation inside the mine) and oriented with a magnetic compass. A profile across the host rock salt and dyke was sampled in detail (Fig. 1b). The salt rock was sampled on the NW and SE sides of the dyke, between a distance of 5 to 220 cm and 10 to 75 cm of dyke margins, respectively. The dyke was also sampled along a complete cross-section. Additionally, the regional salt (hosting the dyke) was sampled in three distinct stations, each one sampled along several tens of metres and at the distance of 200–300 m from the studied dyke.

3. Rock magnetism

Detailed magnetic mineralogy studies were carried out, comprising thermomagnetic and classical hysteresis analyses.

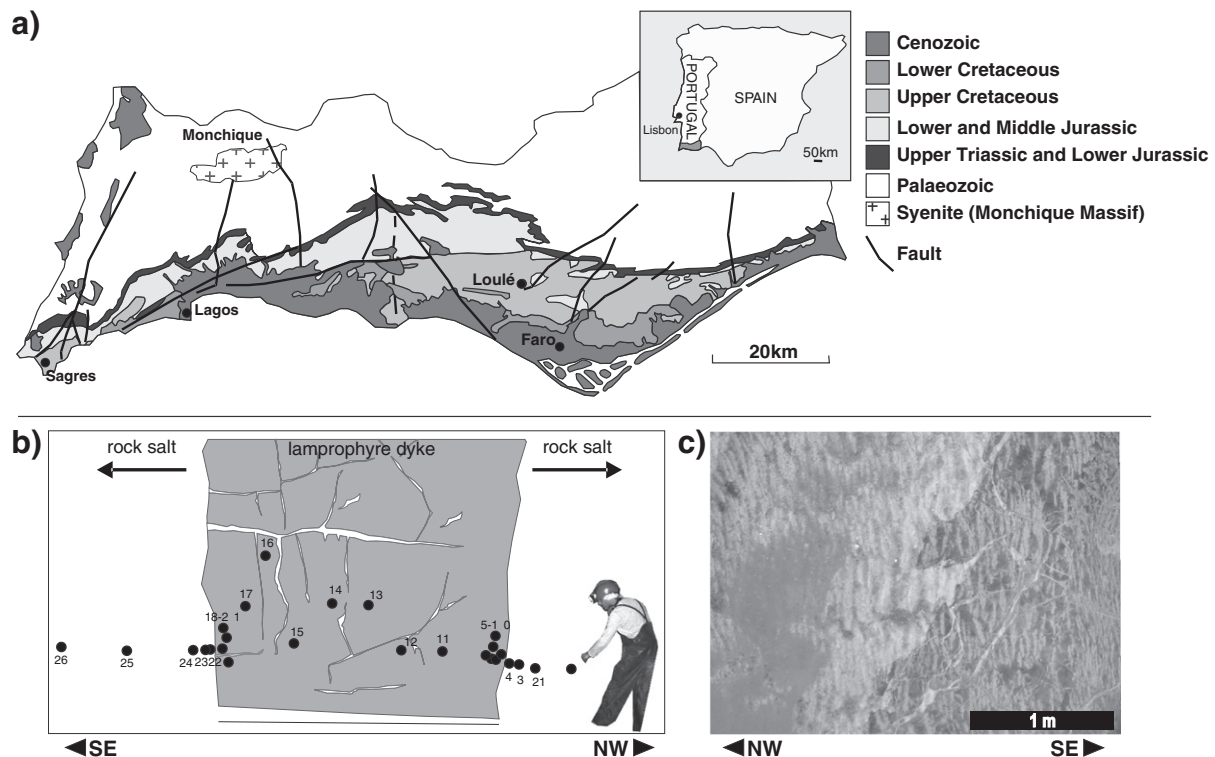


Fig. 1. Geology of the studied area. a) Simplified geological map showing the location and regional geology of the Algarve basin after Borges et al. (2012). b) Position of profile within the dyke and salt-rock system and the numbers and position of individual samples. c) Detailed photographs of the contact between the rock salt and the lamprophyre dyke.

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